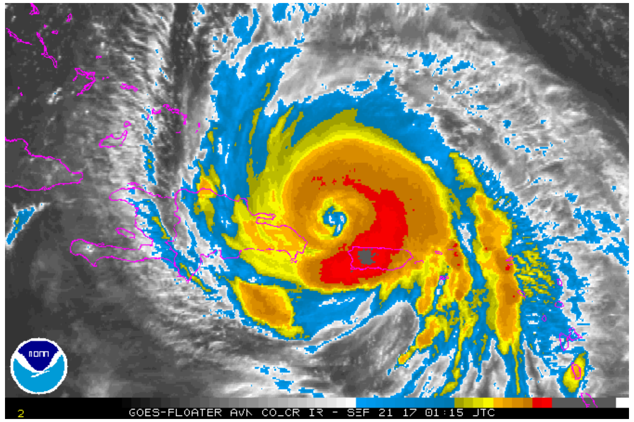
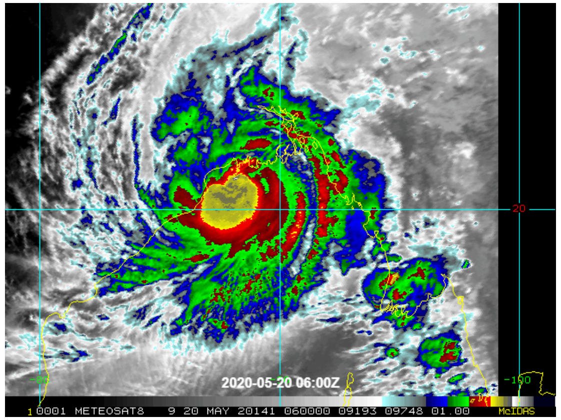
Differential-Power-Processing-Based Microgrid Architectures using Control Co-design

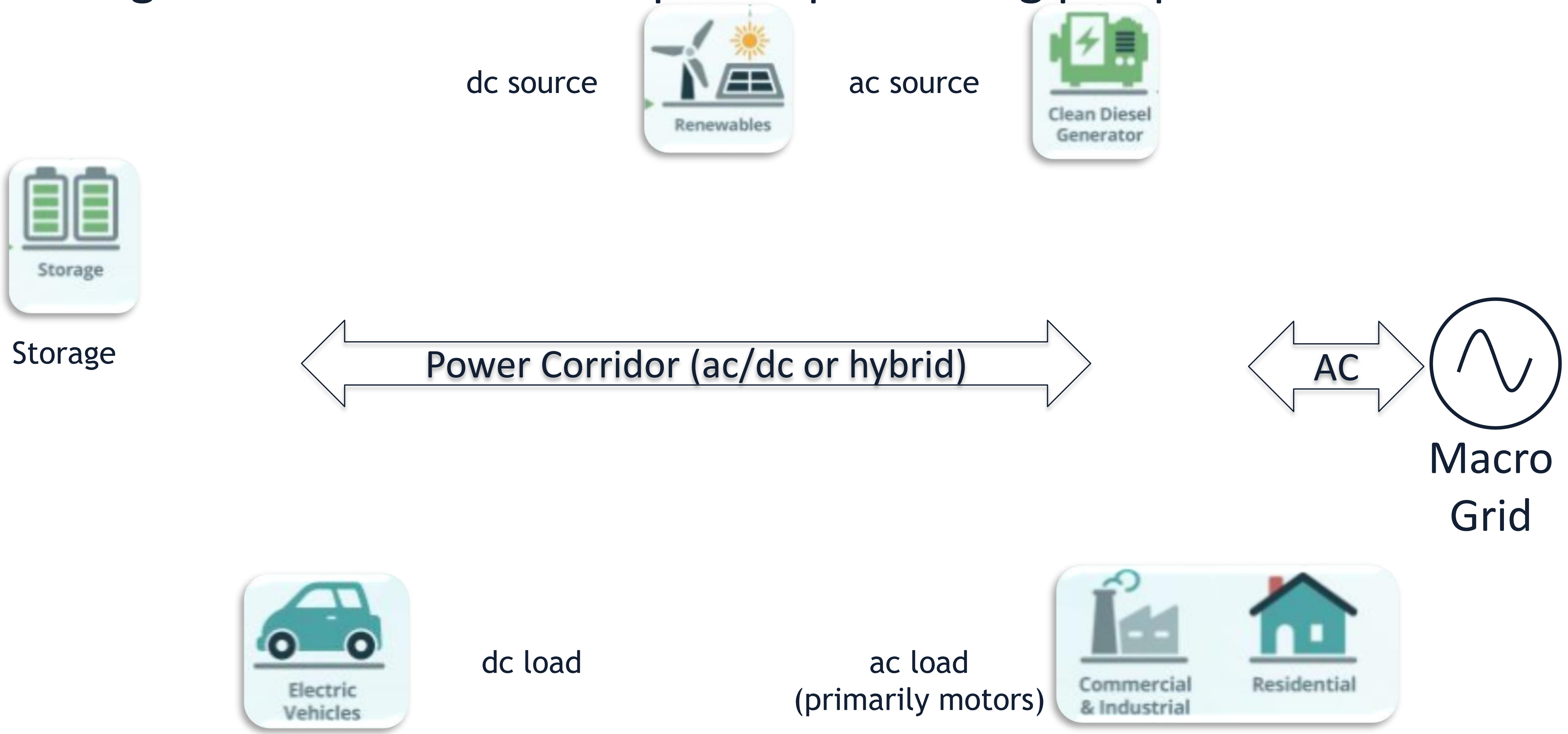




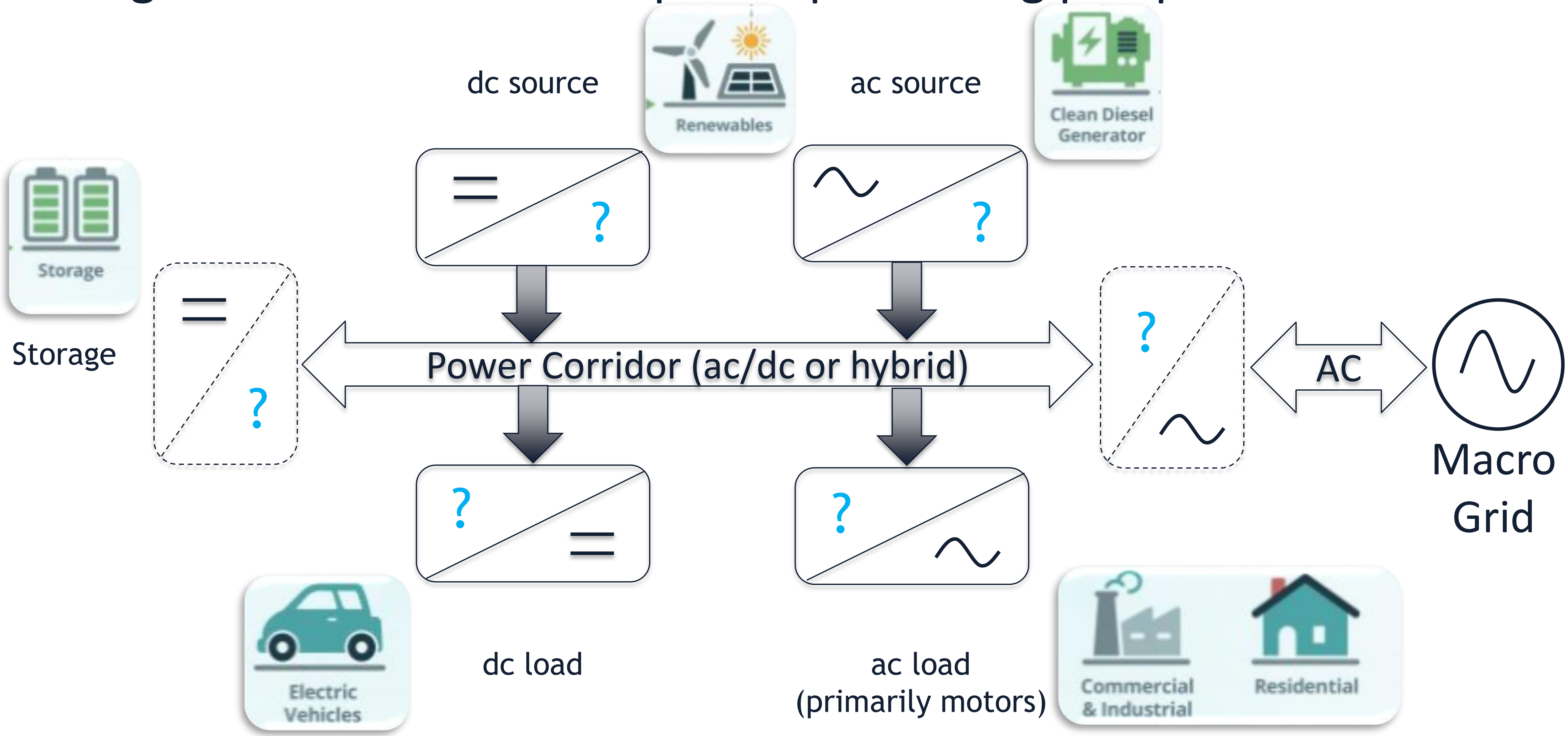
Dr. Arijit Banerjee

University of Illinois at Urbana-Champaign

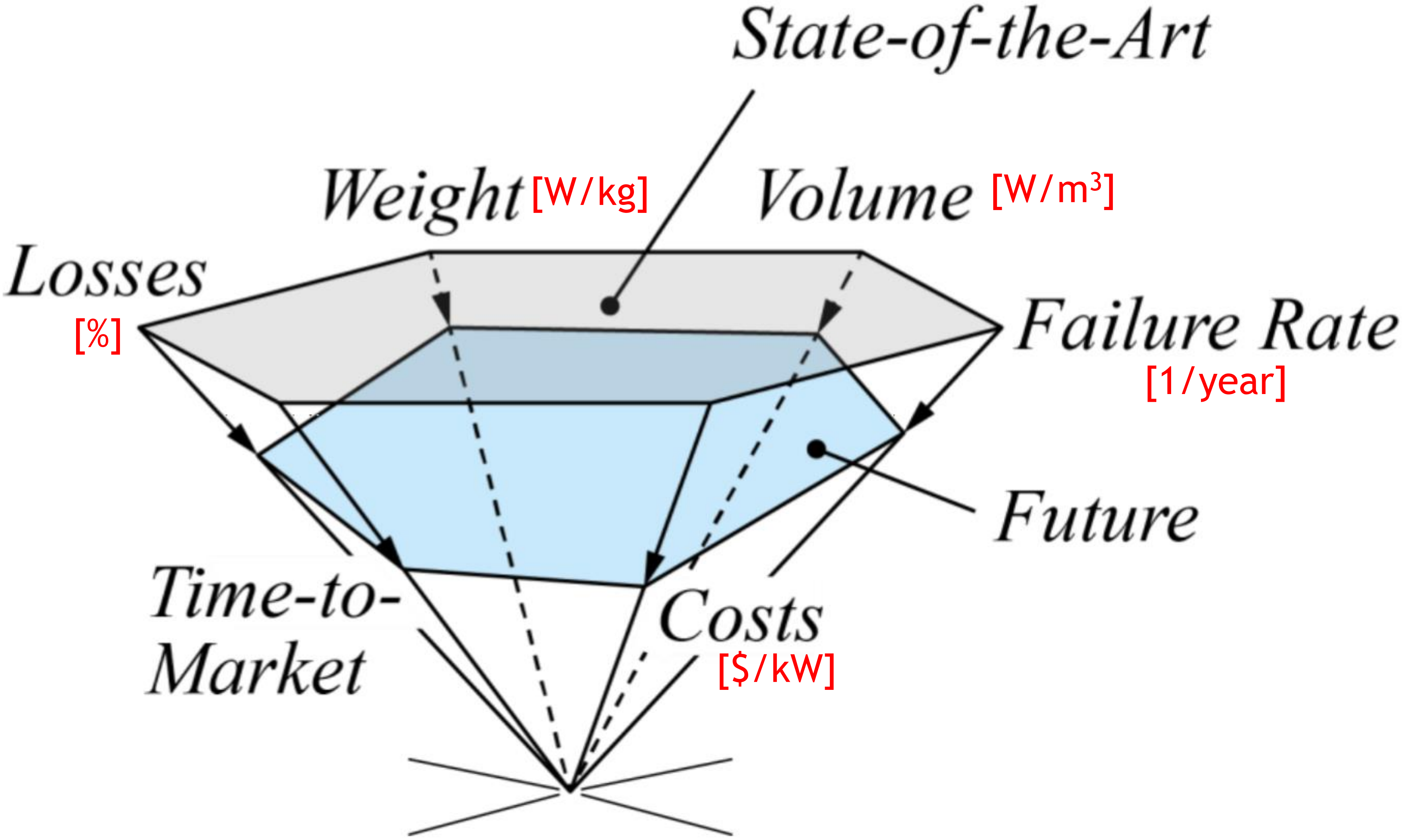
Microgrid abstraction from a power processing perspective



Microgrid abstraction from a power processing perspective

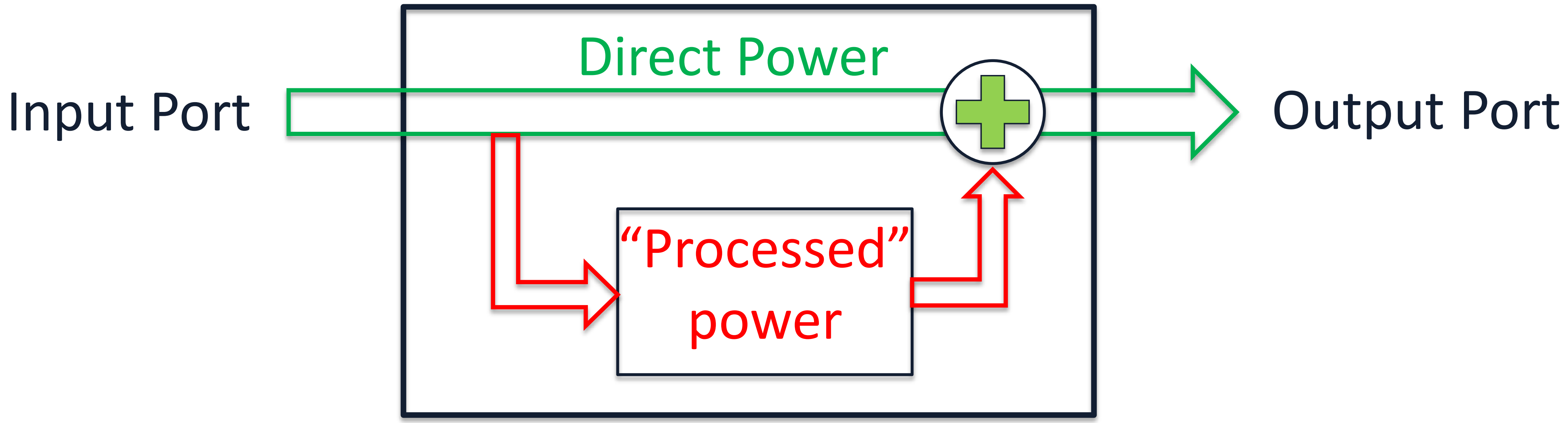


Objective: Improve performance metrics for the power electronics



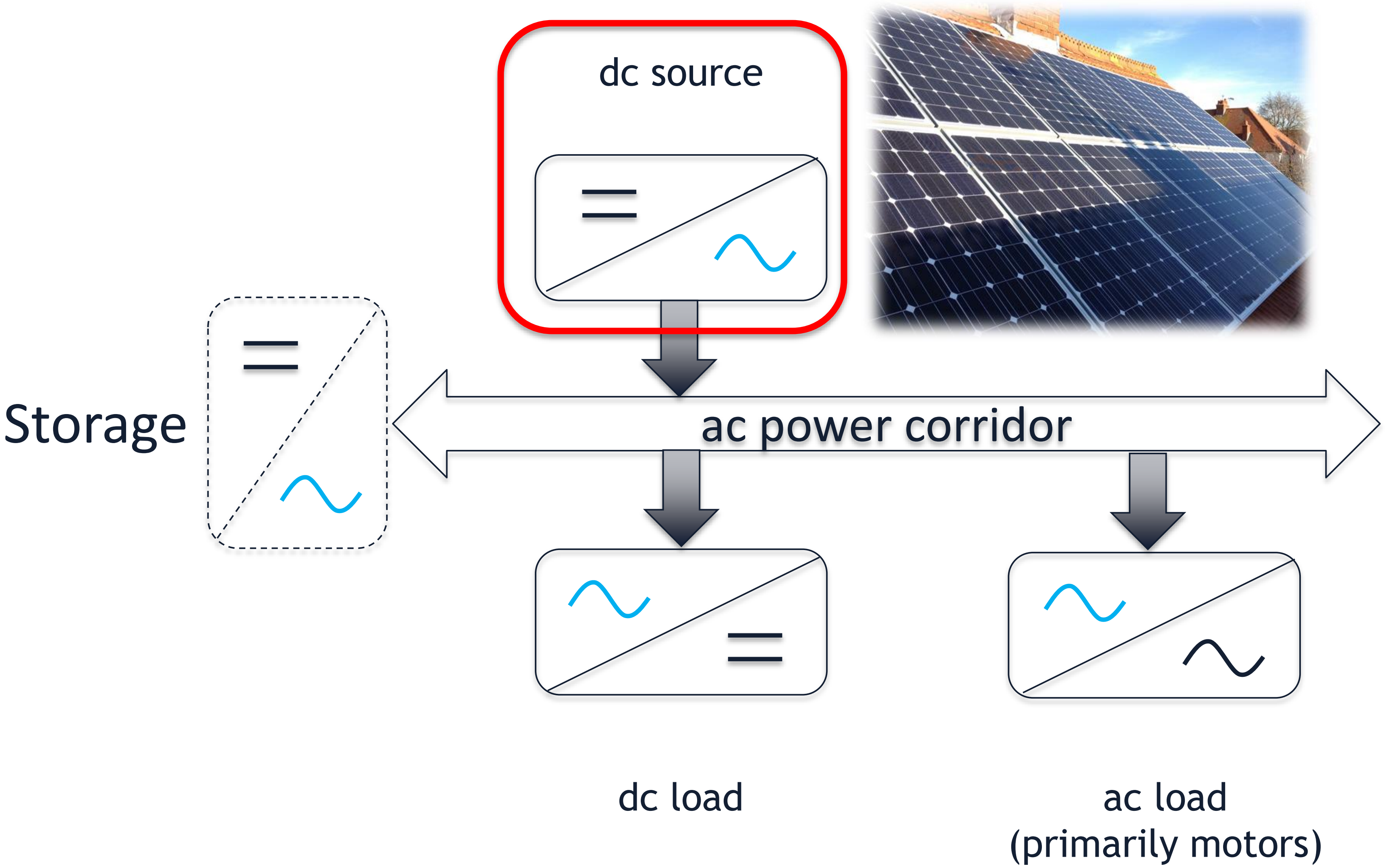
J.W. Kolar, "Future of Power Electronics Circuits," FEPPCON 2019 Norway

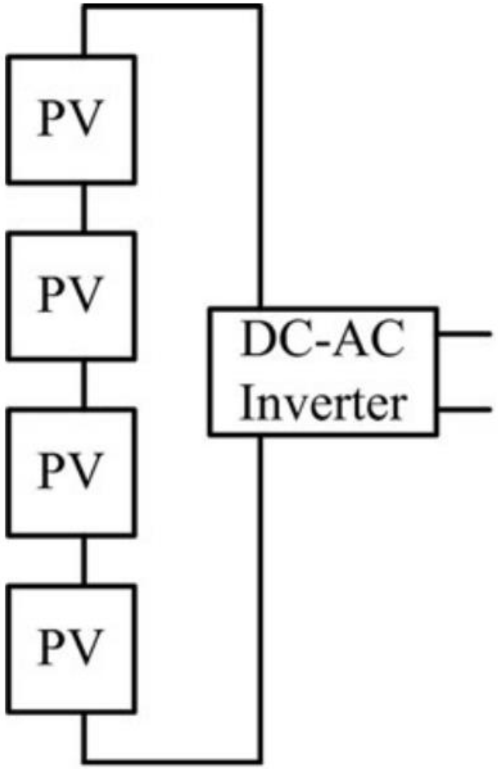
Fundamental limit: Differential power processing



J. A. Cobos, H. Cristóbal, D. Serrano, R. Ramos, J. A. Oliver and P. Alou, "Differential power as a metric to optimize power converters and architectures," 2017 IEEE Energy Conversion Congress and Exposition (ECCE), Cincinnati, OH, 2017, pp. 2168-2175

Example 1: Differential power processing for solar + ac power corridor





Series string of PV with central inverter

P. S. Shenoy, K. A. Kim, B. B. Johnson and P. T. Krein, "Differential Power Processing for Increased Energy Production and Reliability of Photovoltaic Systems," in IEEE Transactions on Power Electronics, vol. 28, no. 6, pp. 2968-2979, June 2013

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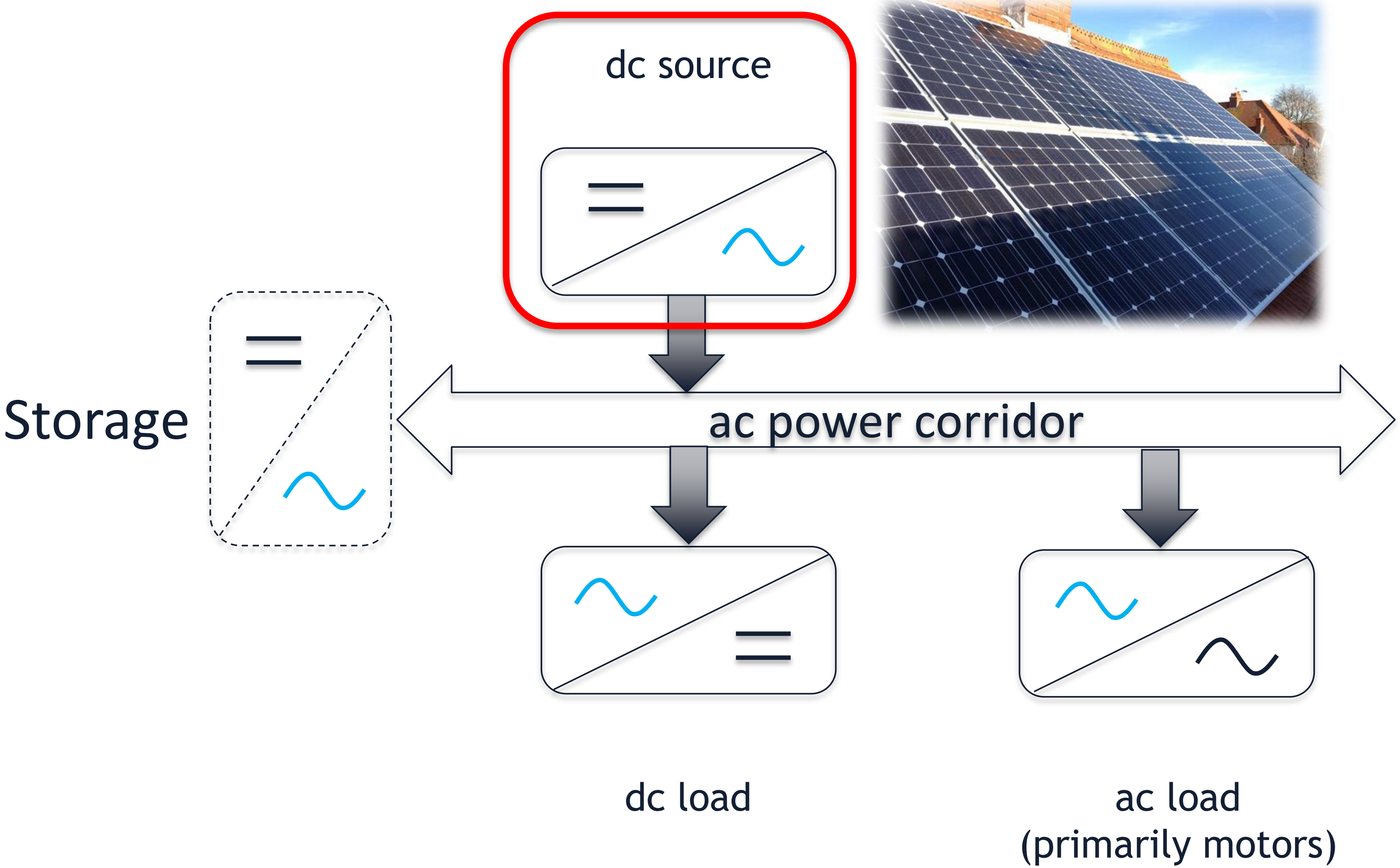

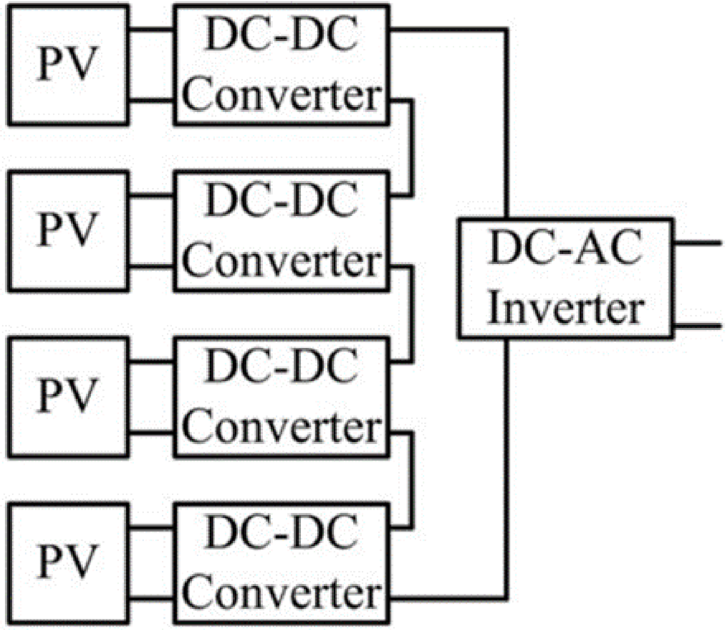

Modular cascaded dc-dc converters with a central inverter

P. S. Shenoy, K. A. Kim, B. B. Johnson and P. T. Krein, "Differential Power Processing for Increased Energy Production and Reliability of Photovoltaic Systems," in IEEE Transactions on Power Electronics, vol. 28, no. 6, pp. 2968-2979, June 2013

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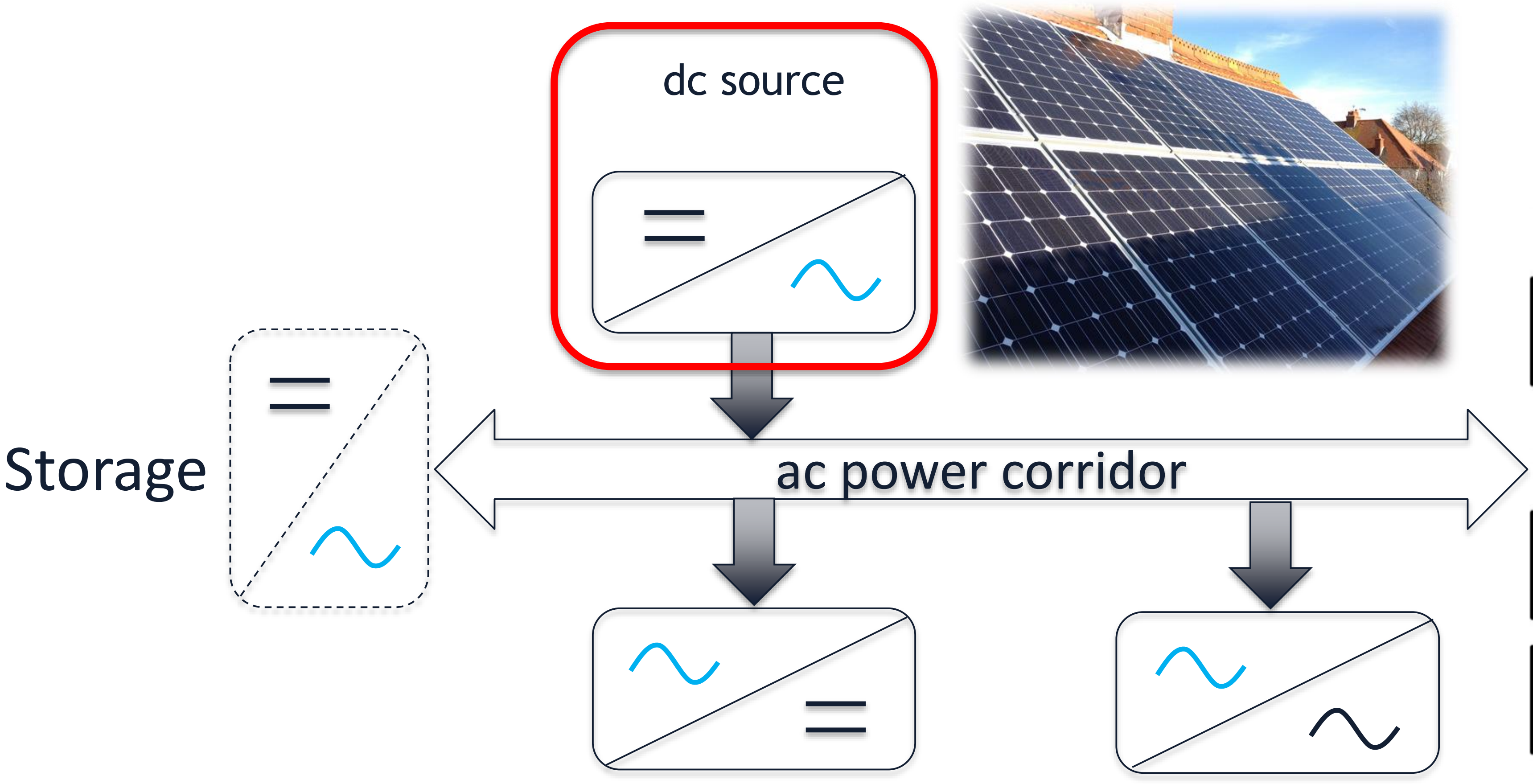
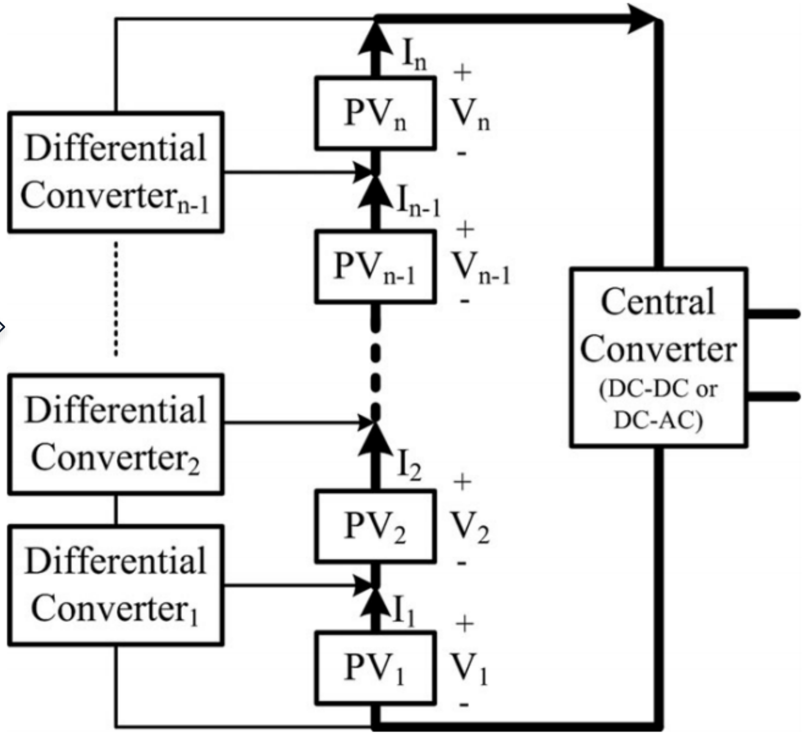


dc load

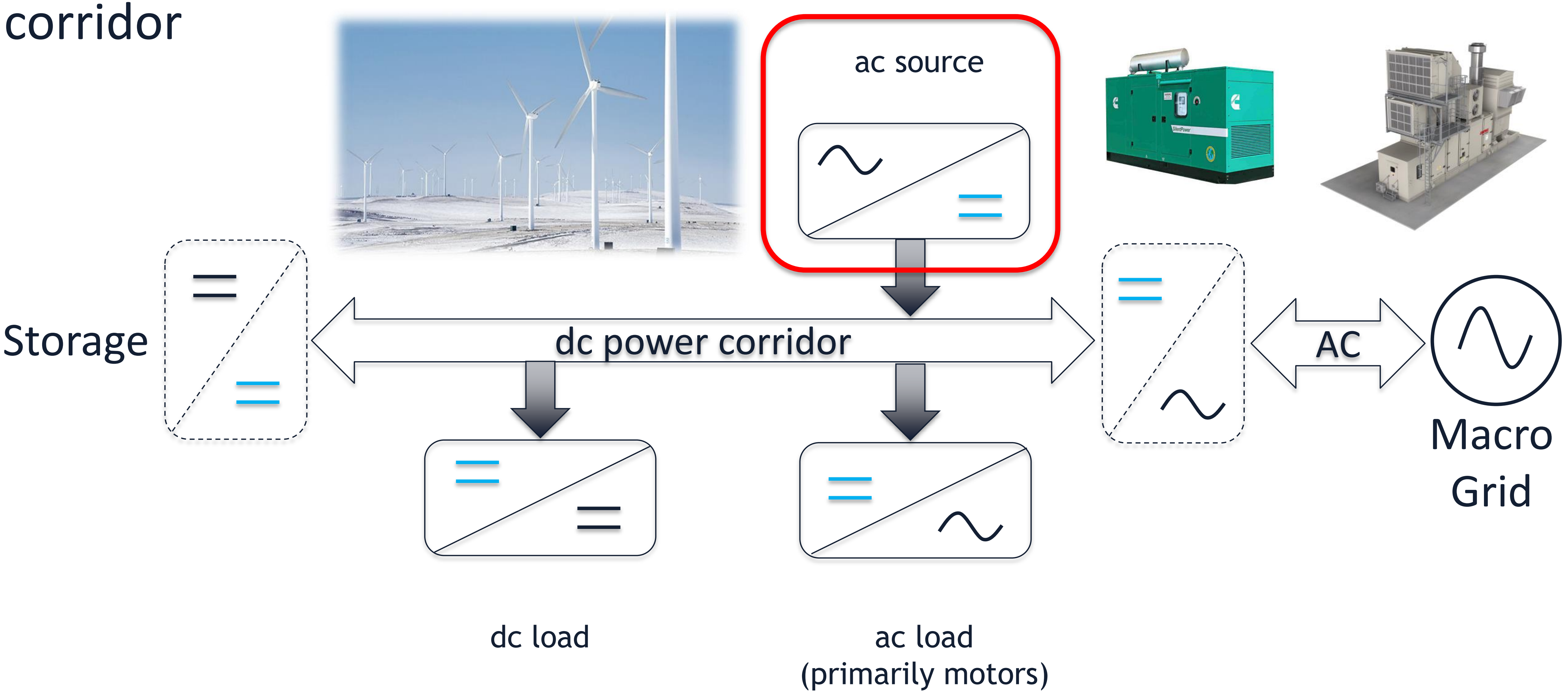
ac load
(primarily motors)



Each PV to operate at its local maximum power extraction without processing total PV power

P. S. Shenoy, K. A. Kim, B. B. Johnson and P. T. Krein, "Differential Power Processing for Increased Energy Production and Reliability of Photovoltaic Systems," in IEEE Transactions on Power Electronics, vol. 28, no. 6, pp. 2968-2979, June 2013

Example 2: Differential power processing for gas/wind turbine + dc power corridor



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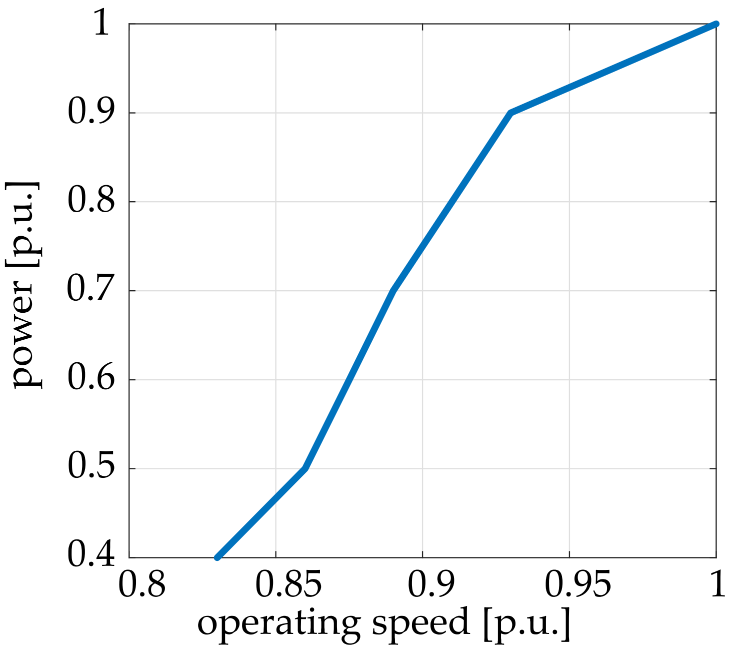
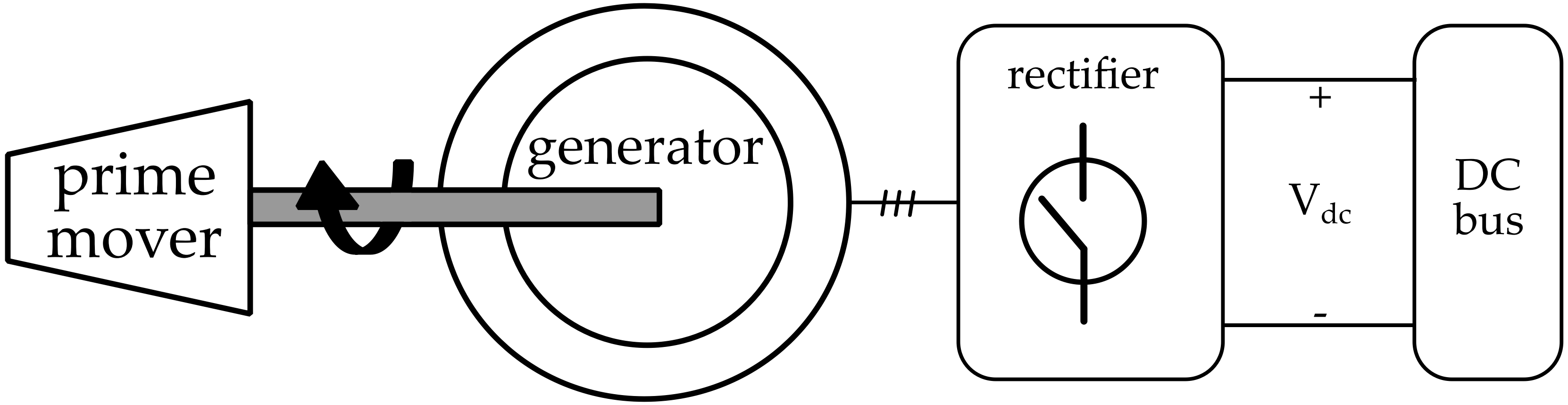
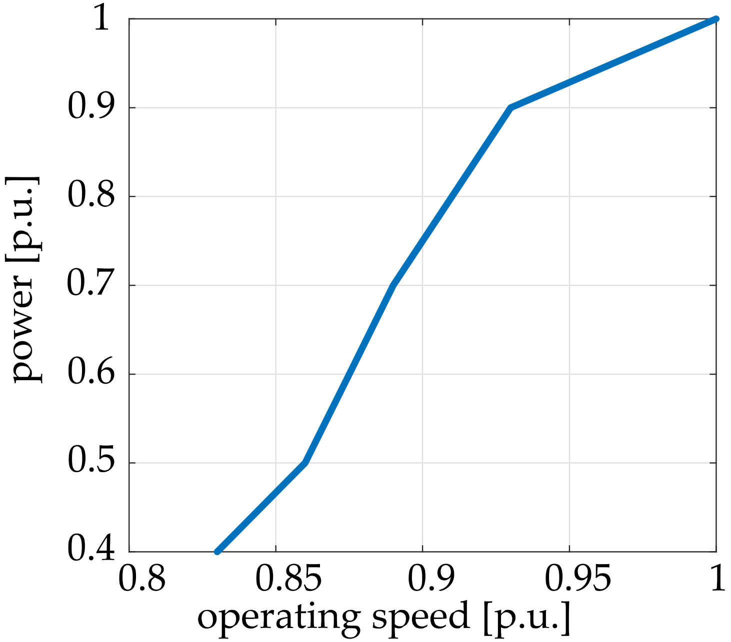


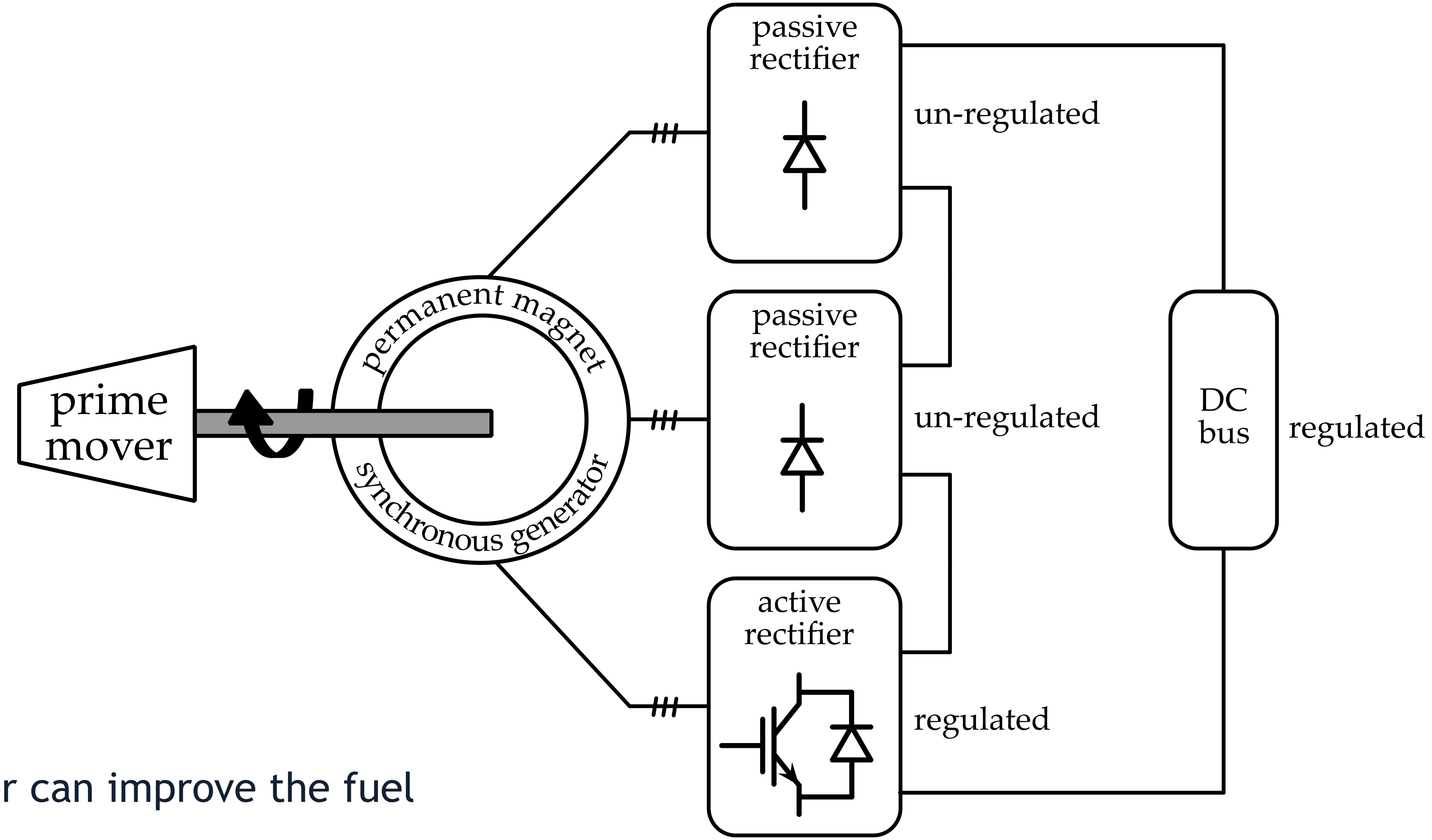


Varying speed of a diesel generator can improve the fuel efficiency by 3% at light load

F. Mura, R. W. D. Doncker, B. Persigehl, P. Jeschke, and K. Hameyer, "Analysis of a gearless medium-voltage variable speed gas turbine," VGB, Tech. Rep., 2011.

Example 2: Differential power processing for gas/wind turbine + dc power corridor

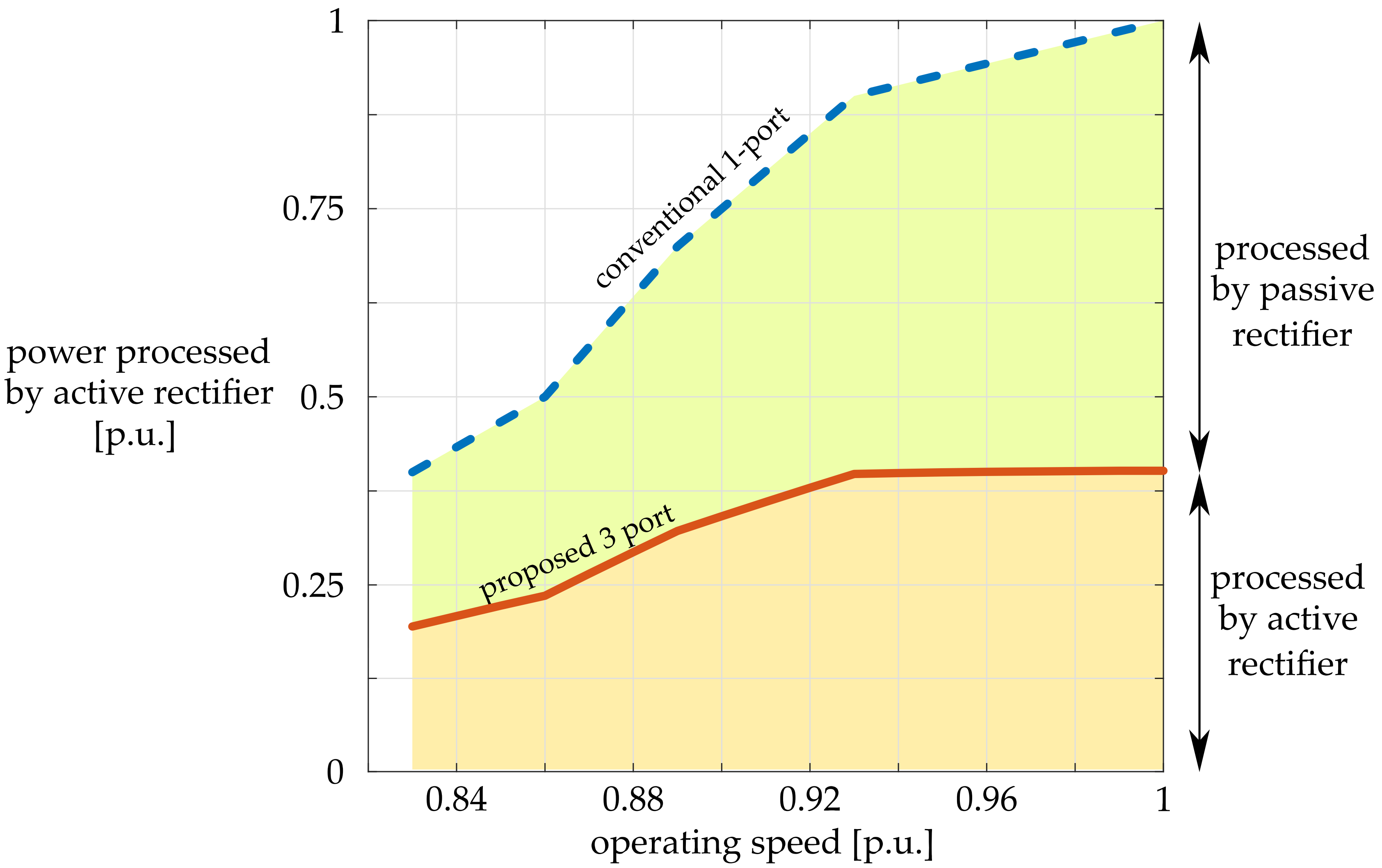




Varying speed of a diesel generator can improve the fuel efficiency by 3% at light load

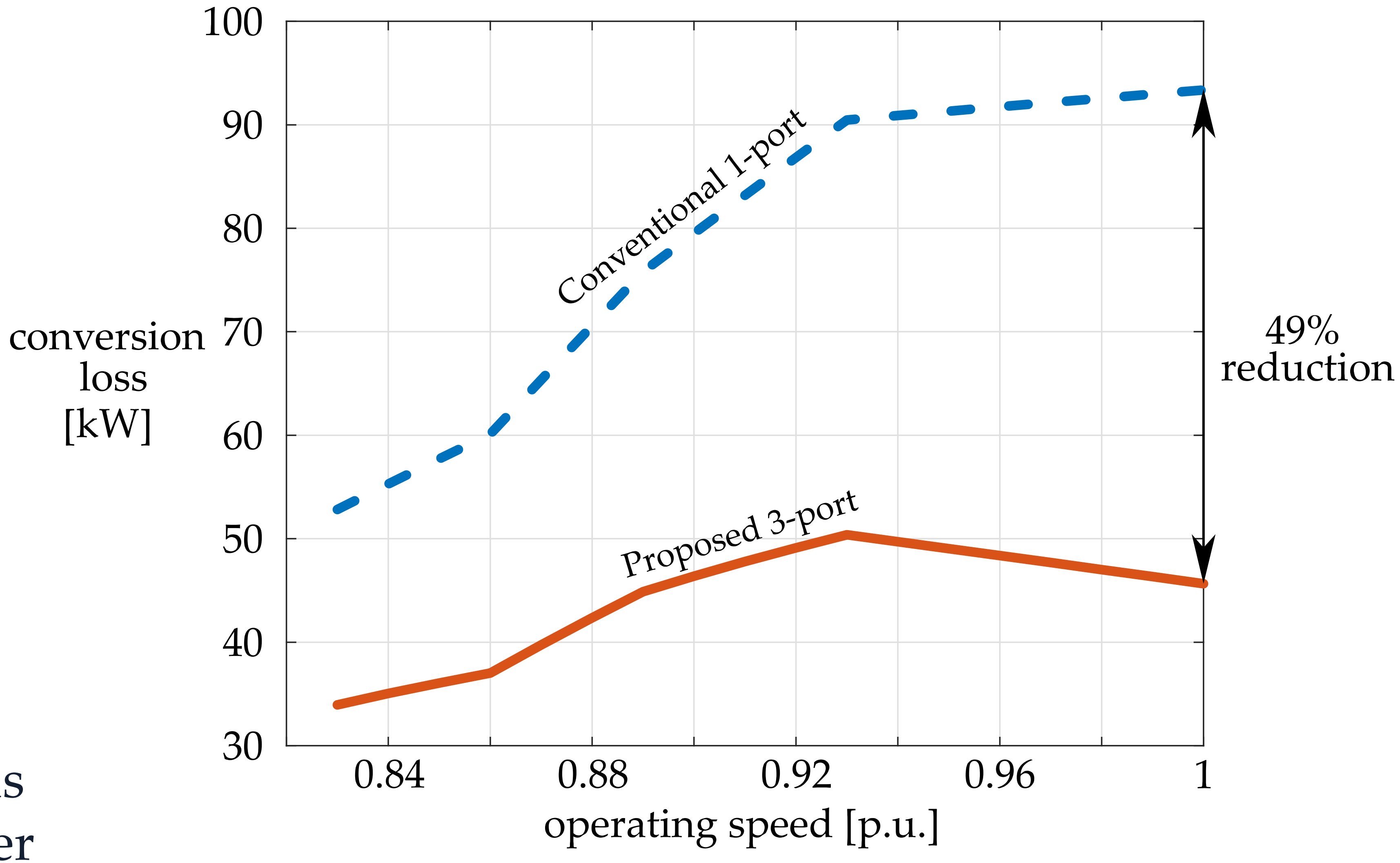
P. T. Huynh, P. J. Wang and A. Banerjee, "An Integrated Permanent-Magnet-Synchronous Generator-Rectifier Architecture for Limited-Speed-Range Applications," in IEEE Transactions on Power Electronics, vol. 35, no. 5, pp. 4767-4779, May 2020.

60% of the power processed relatively inexpensively and more reliably



P. Huynh and A. Banerjee, “Integrated Generator-Rectifier for Electric Ship DC Power System,” 2019 IEEE Electric Ship Technologies Symposium (ESTS), Washington, DC, USA, 2019, pp. 592-598.

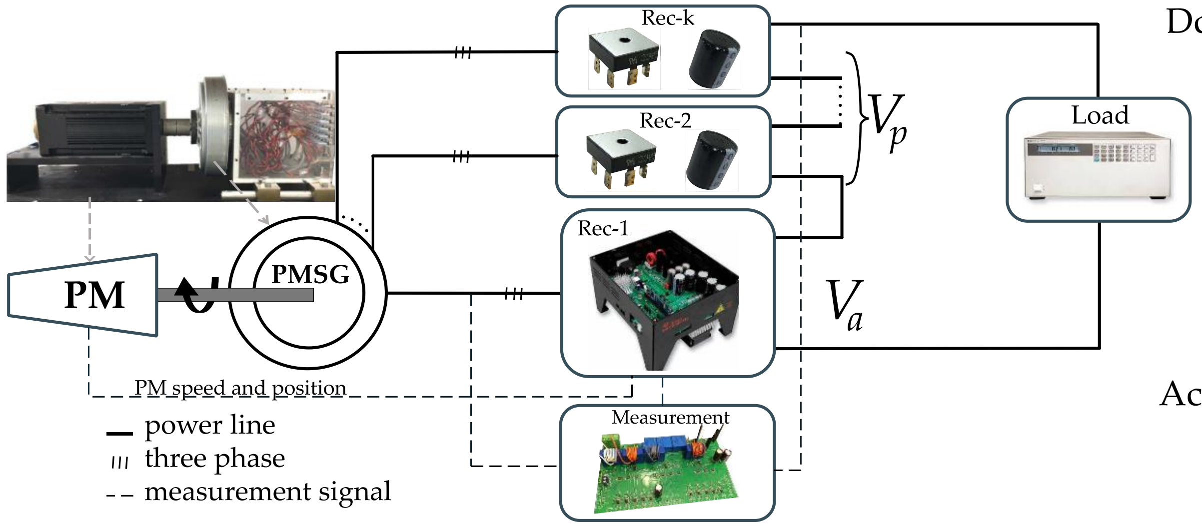
Conversion loss is nearly half at the rated operating condition

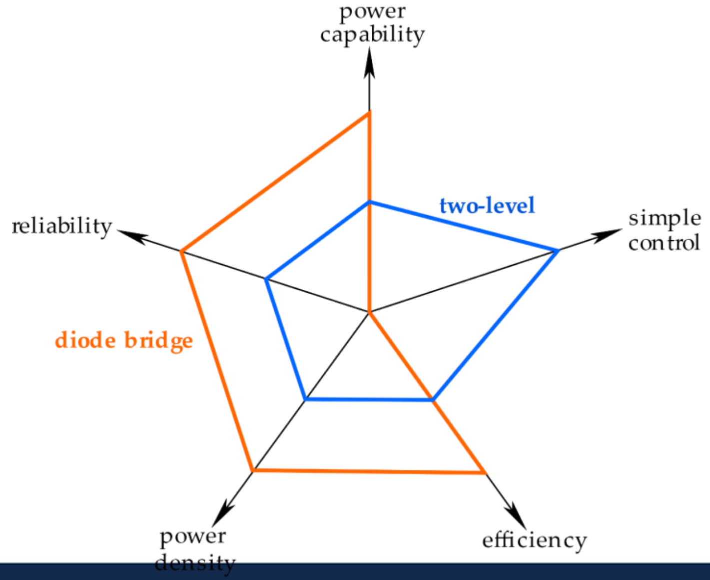


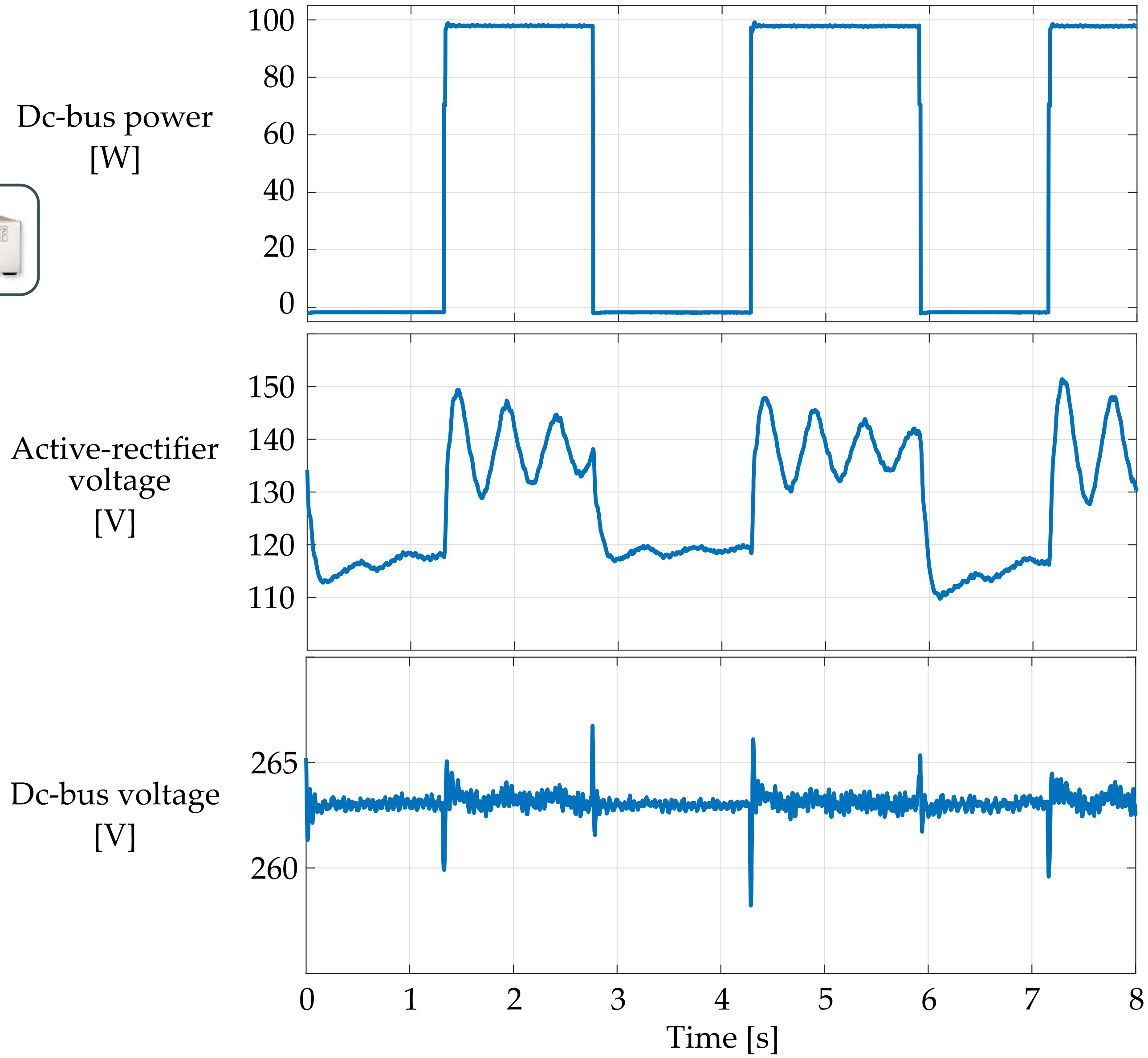
6 kV DC bus
3 MW power

P. Huynh and A. Banerjee, "Integrated Generator-Rectifier for Electric Ship DC Power System," 2019 IEEE Electric Ship Technologies Symposium (ESTS), Washington, DC, USA, 2019, pp. 592-598.

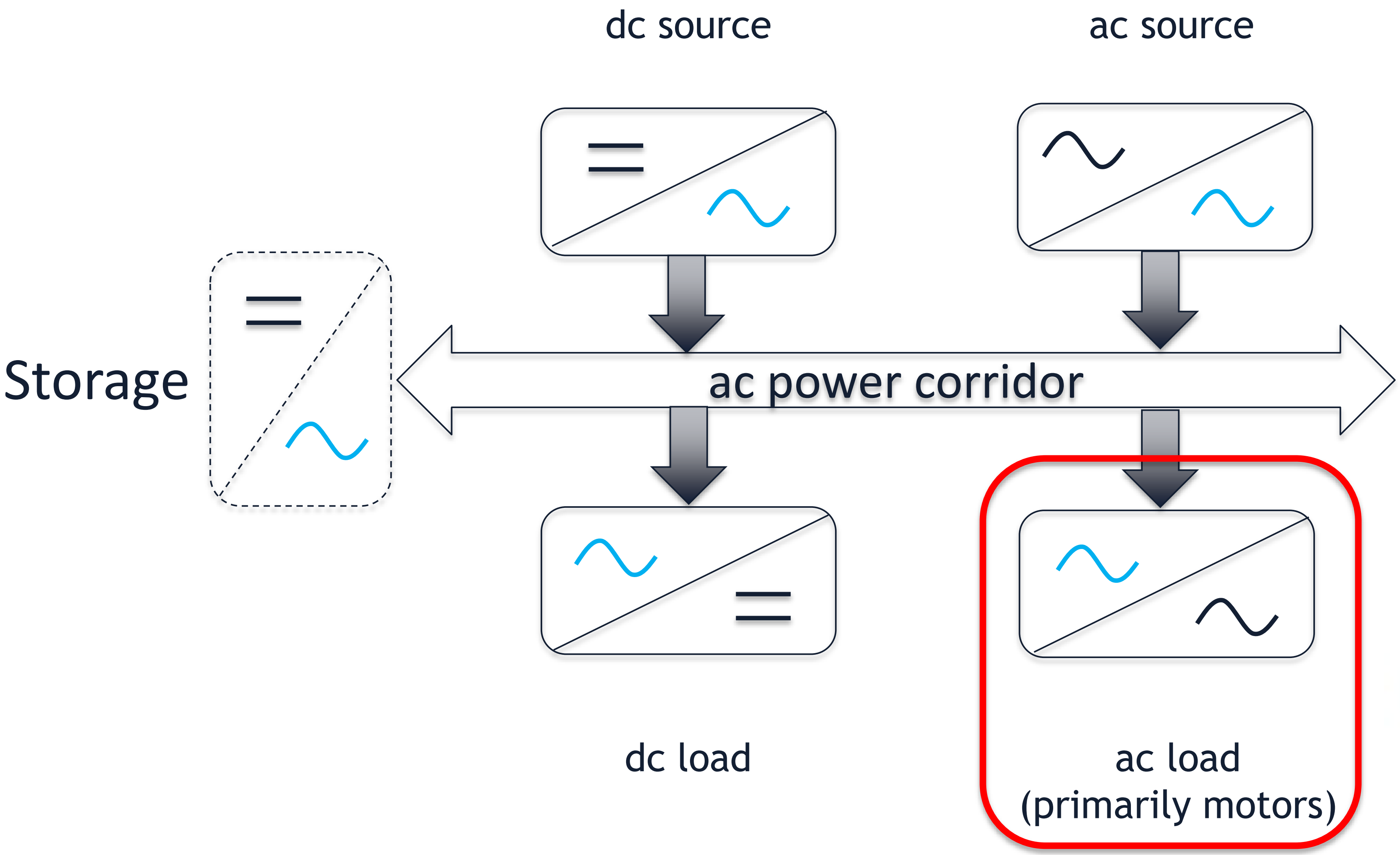
Key enabler: Control Co-design







Example 3: ac power corridor + propulsion motor



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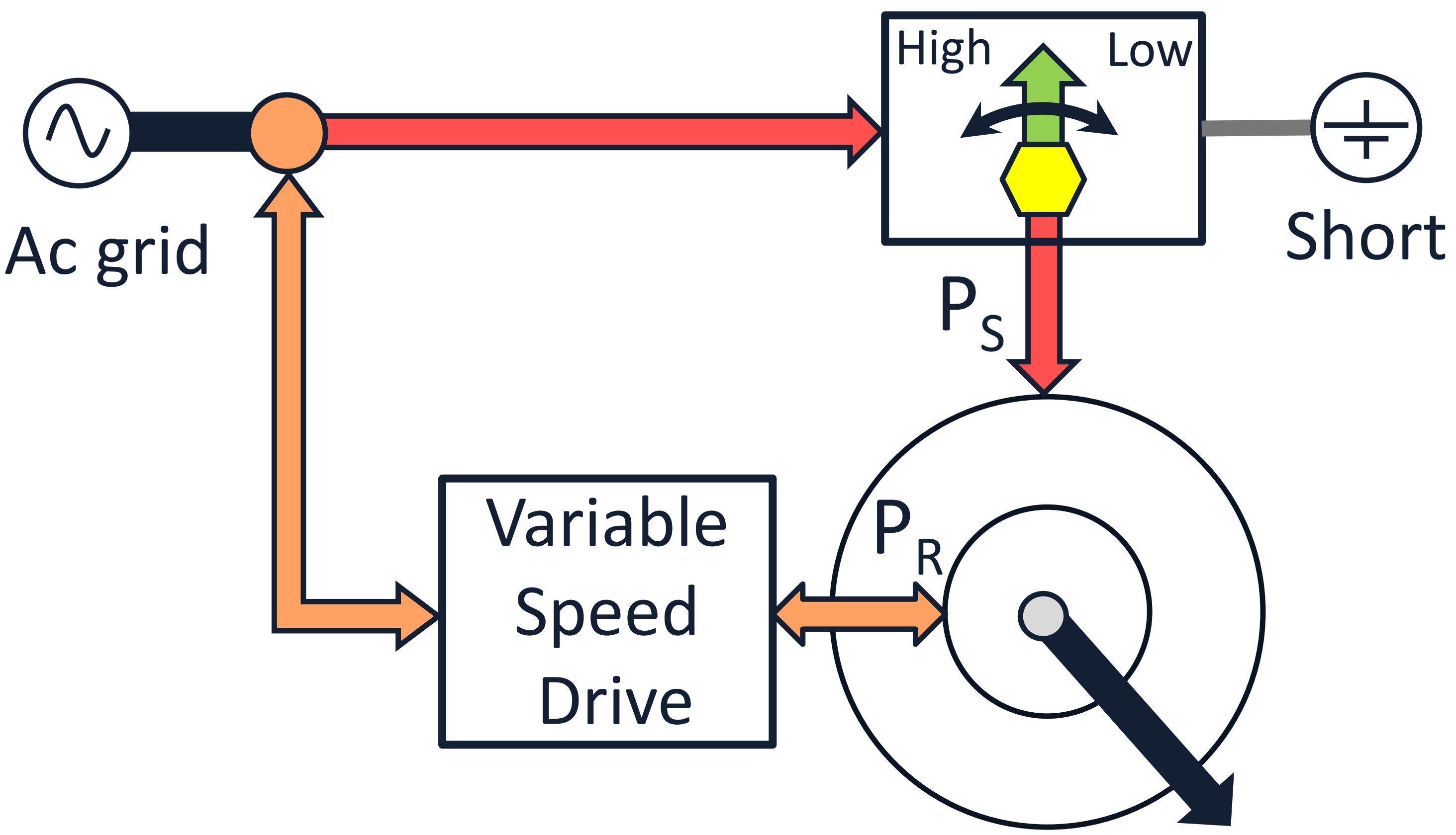
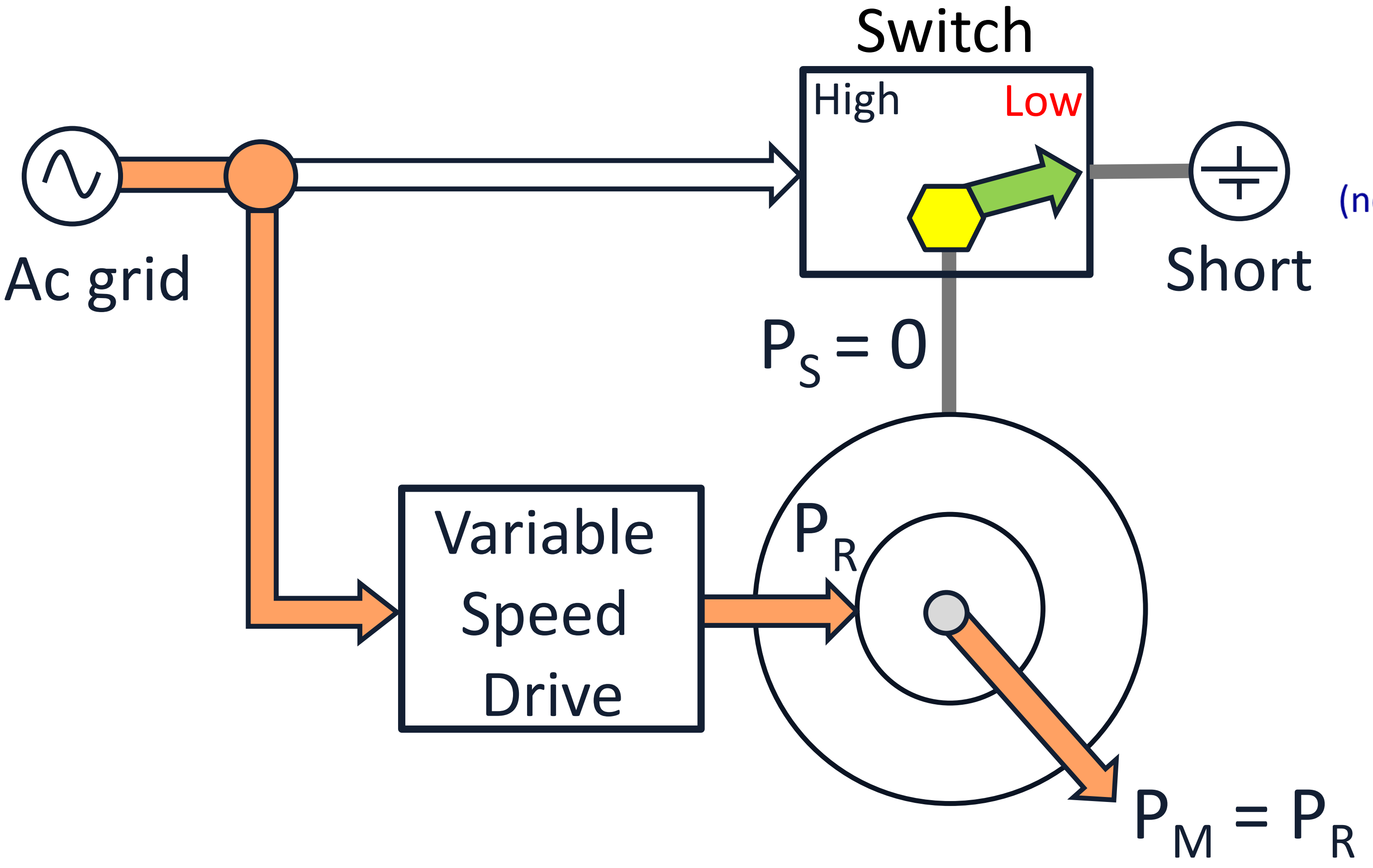
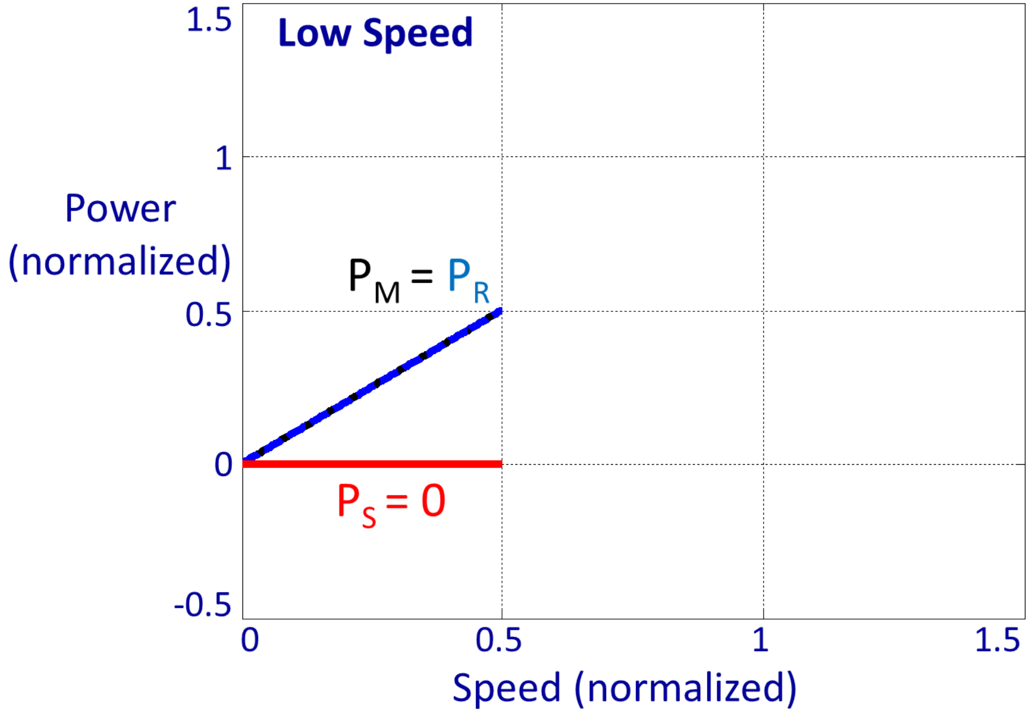


A. Banerjee, M. S. Tomovich, S. B. Leeb, and J. L. Kirtley, “Power Converter Sizing for a Switched Doubly-Fed Machine Propulsion Drive,” in IEEE Transactions on Industry Applications, vol. 51, no. 1, pp. 248-258, Jan.-Feb. 2015.

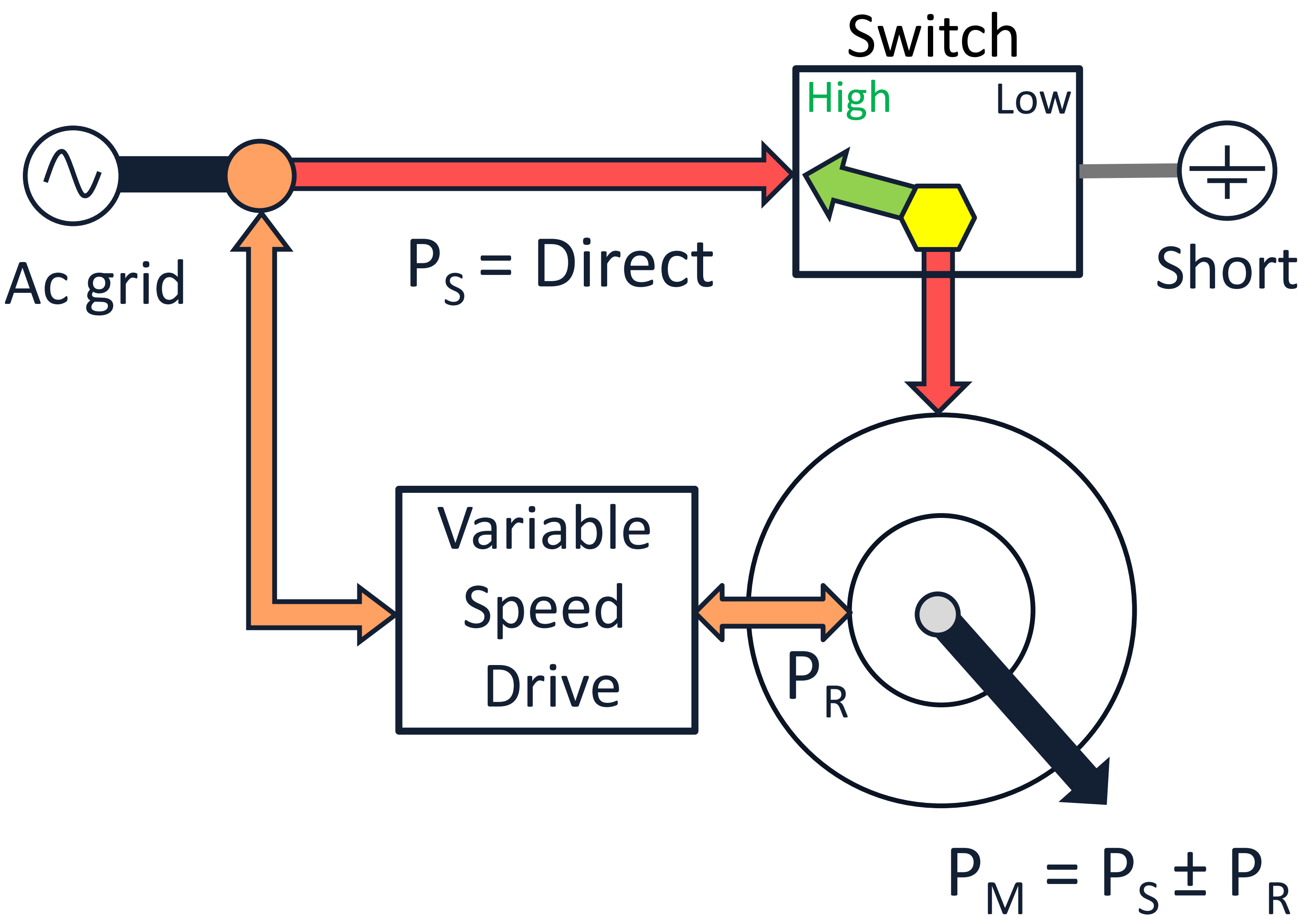
Switch is turned "Low" during low-speed, low-power mode

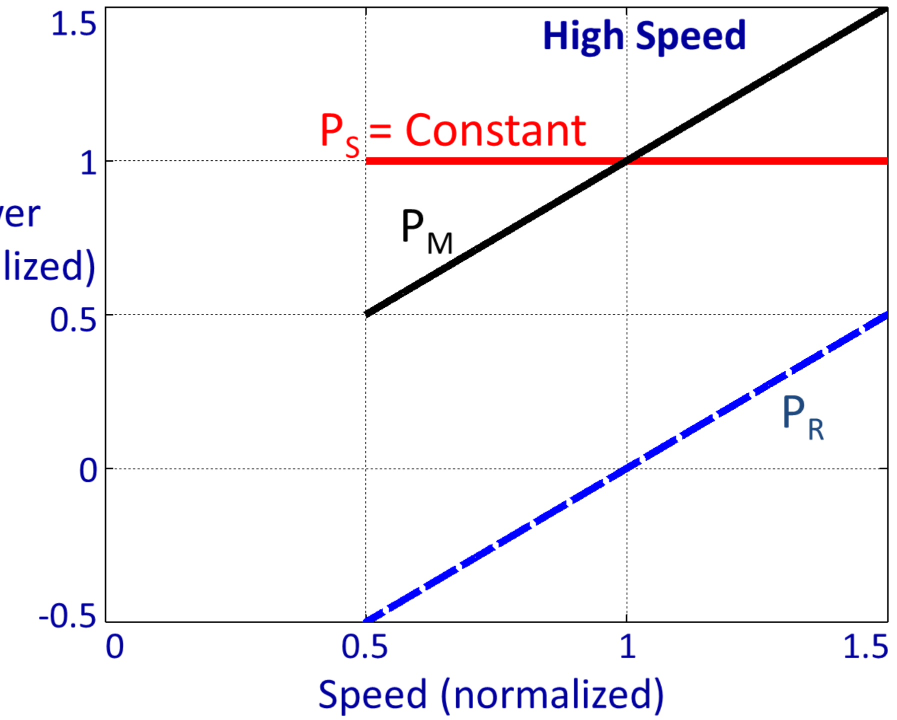




A. Banerjee, M. S. Tomovich, S. B. Leeb, and J. L. Kirtley, "Power Converter Sizing for a Switched Doubly-Fed Machine Propulsion Drive," in IEEE Transactions on Industry Applications, vol. 51, no. 1, pp. 248-258, Jan.-Feb. 2015.

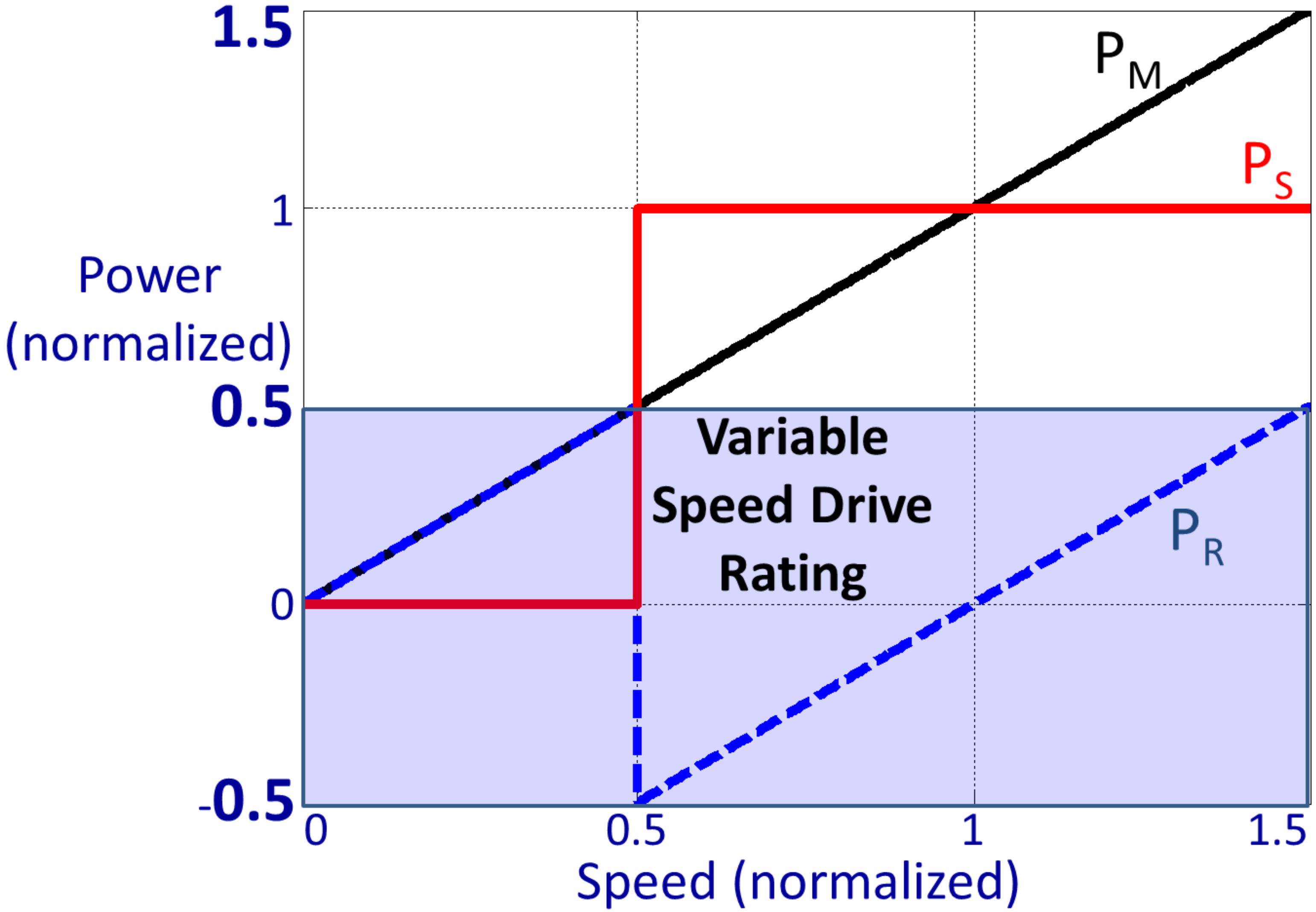
Switch is turned "High" during high-speed, high-power mode





A. Banerjee, M. S. Tomovich, S. B. Leeb, and J. L. Kirtley, "Power Converter Sizing for a Switched Doubly-Fed Machine Propulsion Drive," in IEEE Transactions on Industry Applications, vol. 51, no. 1, pp. 248-258, Jan.-Feb. 2015.

Size of variable speed drive reduces by two-thirds

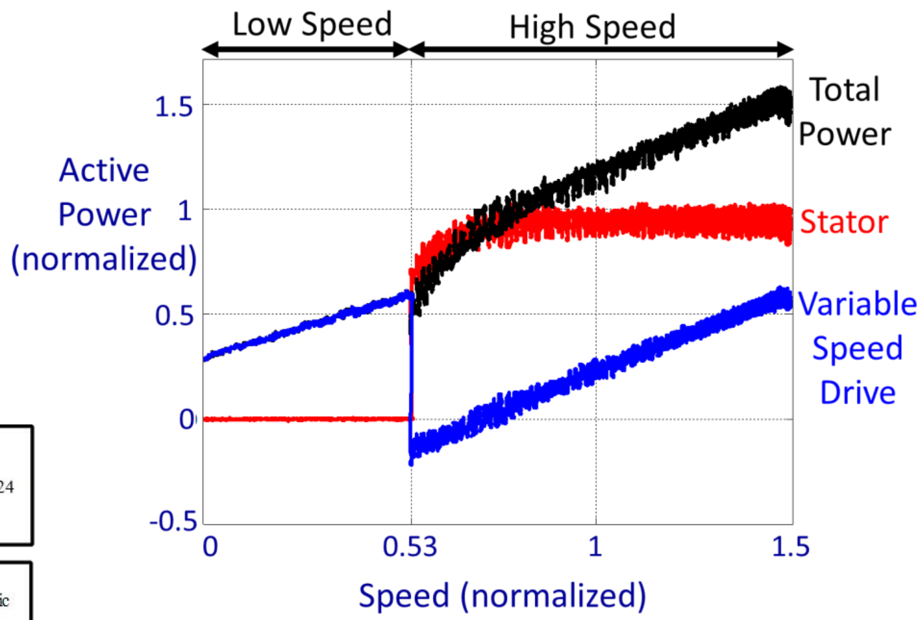


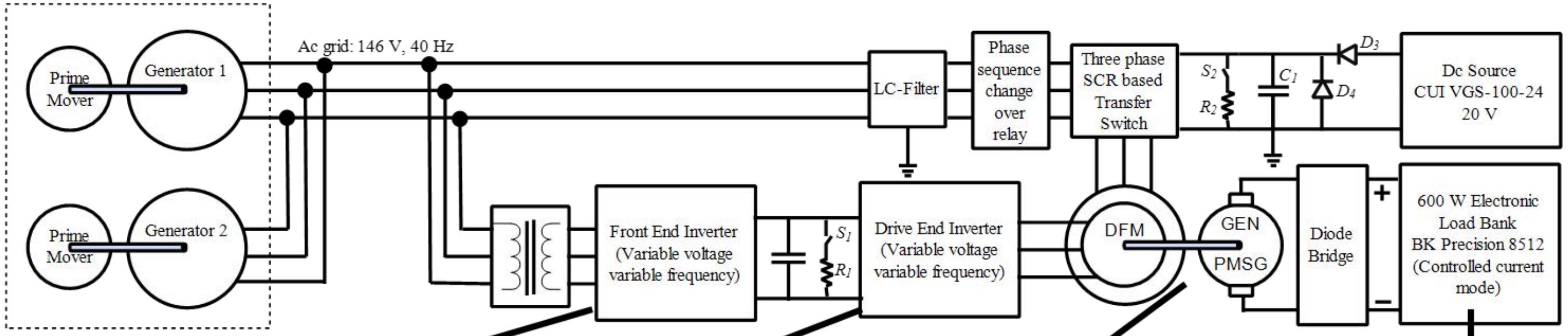
A. Banerjee, M. S. Tomovich, S. B. Leeb, and J. L. Kirtley, "Control Architecture for a Switched Doubly-Fed Machine Propulsion Drive," in IEEE Transactions on Industry Applications, vol. 51, no. 2, pp. 1538-1550, March-April 2015.

Laboratory-scaled ship power system

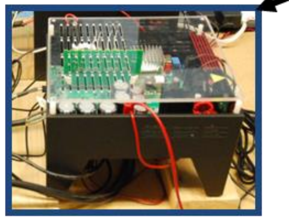
Generators (1.4 kW)

6 Machines
5 Control platforms (TI, NI, Matlab RTW, PSoC)
3 Data acquisition systems
2 Converters + Filters





Grid-side Conv.



TI C2000

PM Gen. DFM (1.1 kW)

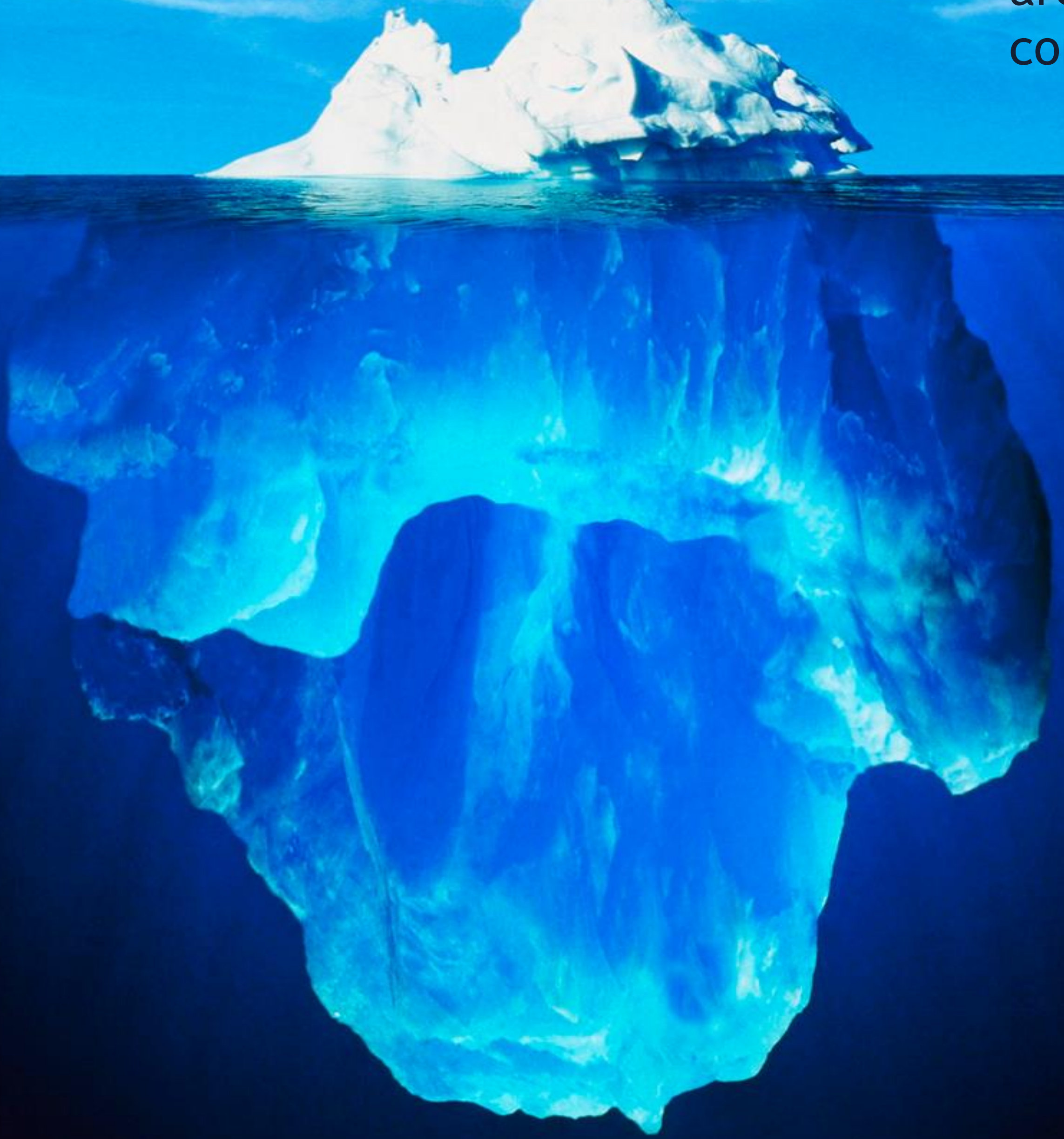
DC Electronic Load Bank

A. Banerjee, A. H. Chang, K. N. Surakitbovorn, S. B. Leeb, and J. L. Kirtley, "Bumpless Automatic Transfer for a Switched-Doubly-Fed-Machine Propulsion Drive," in IEEE Transactions on Industry Applications, vol. 51, no. 4, pp. 3147-3158, July-Aug. 2015.

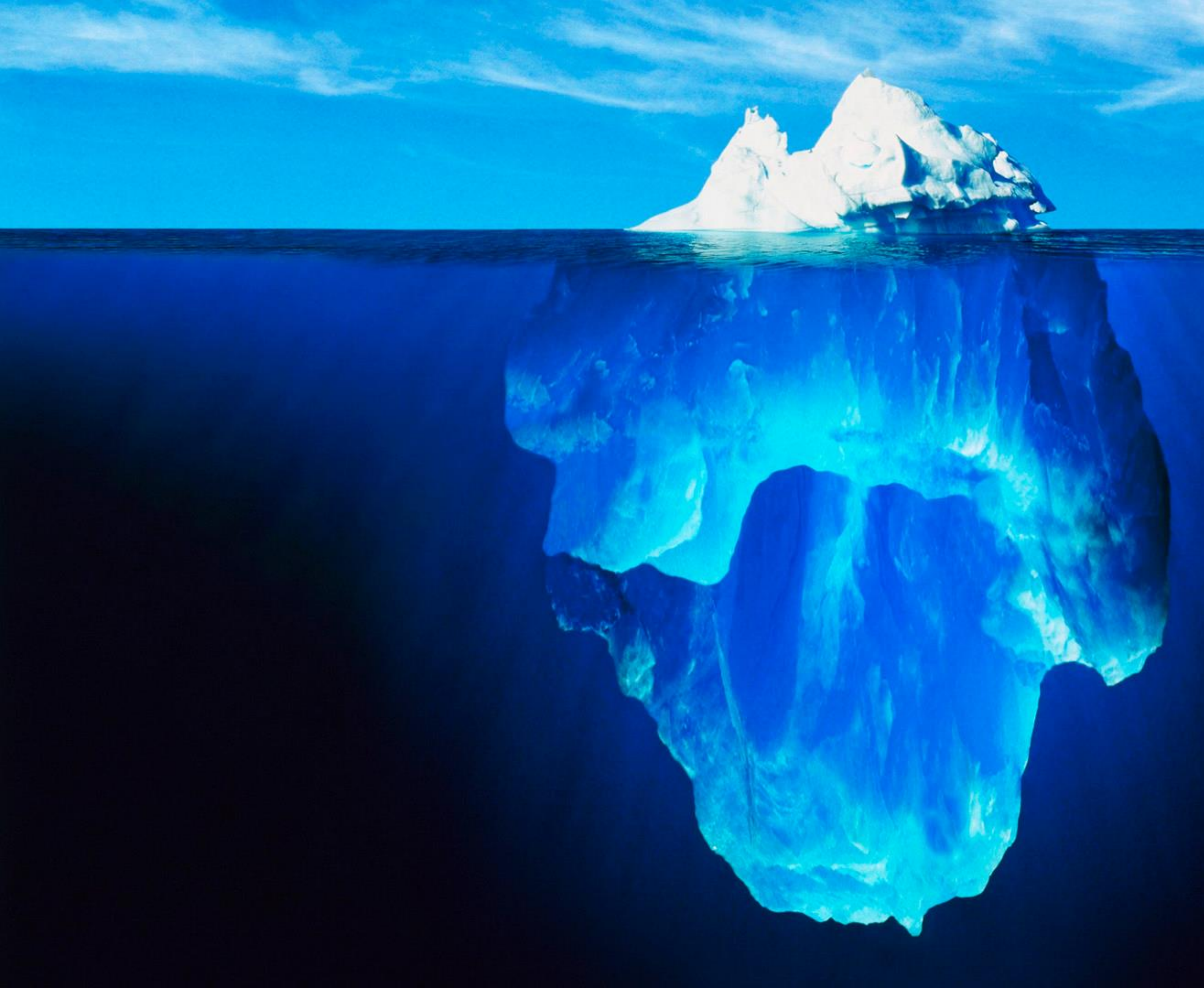
Summary and Challenges

Differential/partial processing architecture inherently relies on control co-design

Solutions are case-by-case basis



- What kind of power corridor is better?
- How can we have a holistic approach to create microgrid power network architecture ?
- How do we take advantage of differential power processing to enable control co-design and achieve control objectives (Ref: Mario’s slide)?



Thank you!

Contact:
arijit@illinois.edu